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Yield stress of unclassified tailings paste based on L-Box method

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Abstract

The rheological parameters of unclassified tailings paste were tested by L-Box method and using a vane-rheometer in order to calculate the frictional drag, and then detect the results accuracy of L-Box method. The results show that, yield stress increased from 68.9~73.4 to 212.4~225.1 Pa along with the increase of paste concentration from 72 to 78%. Furthermore, yield stress increased exponentially with slurry concentration and featured a sharp increase when concentration increased from 76 to 78%. The results of L-Box method and vane-rheometer were similar, although that of the latter was slightly greater, with the deviation being 0.65 to 11.89% (its average being 7.18%). The calculated frictional drag was 3.39 ~ 6.6 MPa/km with a backfill capacity of 60 m^3/h, pipe diameter of DN150, and slurry concentration of 74~78%.

1 Introduction

The rheological properties of unclassified tailing paste as a typical non Newtonian fluid (Yin et al., 2012; Jiao et al., 2013) have been characterized by both the Bingham model and H-B model (Shuttleworth and Thomson, 2005; Li et al., 2012). The abundant ultrafine particles contained in the paste form a three dimensional flocculation network under surface physical and chemical actions and they also have certain shear strength (Li et al., 2015), enabling the paste to have both solid and liquid characteristics, i.e. a state of “semisolid” (Shi et al., 2001; Patterson and Lazarus, 1993), and the reason for the non-Newtonian body with yield stress (Wang et al., 2004).

In terms of slurry rheology, hydraulic gradient, as the core of the design of pipeline conveying system, can be determined by two critical parameters, yield stress and viscosity (Li et al., 2012; Xi et al., 2013).

Currently, rheological parameters can be detected by methods such as slurry rheometer, pipe rheometer, coaxial cylinder rheometer, plate viscometer and so on. However, due to different accuracy and adaptability, the results obtained by various methods also differ, hence greatly influencing the rheological characteristics of slurry and the design of paste pipeline conveying system (Jiao et al., 2010).

In the case of a lead-zinc mine tailings in Yunnan, two types of yield stress include the vane-rheometer and

L-Box method were used to detect the different slurry concentrations and the rheological parameters of paste so as to determine the critical concentration and to calculate the detection results of slurry transport-tation resistance.

2 Experimental methods

2.1 The principle of L-Box experiment method

The L-Box size (120 cm in length, 20 cm in width and 15 cm in height) and flow analyses are shown in Figure 1. The yield stress is calculated by flow distance L, final height h_0 and material volume. The calculation method is as follows (Li et al., 2013; Roussel, 2007; N'Guyen et al., 2006):

Set up $A = \frac{2\tau_0}{\rho g l_0}$, $\mu = \frac{2h_0}{l_0}$, the total volume of the material is:

$$V = l_0 \int_0^{l_0} x dh = \frac{l_0^3}{4A}\left(ln(1+u_0) + \frac{u_0(u_0-2)}{2}\right) \quad (1)$$

In a certain volume, carry out L-Box experiment, then:

$$\mathrm{L} = \frac{h_0}{A} + \frac{l_0}{2A} ln\left(\frac{l_0}{l_0+2h_0}\right) \quad (2)$$

$$A = \frac{h_0}{L} + \frac{l_0}{2L} ln\left(\frac{l_0}{l_0+2h_0}\right) \quad (3)$$

$$\tau_0 = \frac{\rho g l_0}{2}\left(\frac{h_0}{L} + \frac{l_0}{2L} ln\left(\frac{l_0}{l_0+2h_0}\right)\right) \quad (4)$$

Where:

ρ = slurry density, t/m^3;

G = the acceleration of gravity, 9.8 m/s^2;

τ_0 = yield stress, Pa;

l_0 = L-Box width;

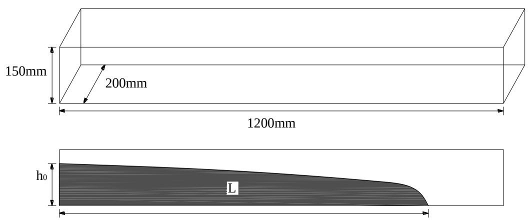

Figure 1 The size of the L-Box and the force analyses of flow

2.2 The yield stress of unclassified tailings paste

The detection principle of Brookfield R/S rotary rheometer is shown in Figure 2 (Alderman and Meeten, 1991; Nguyen, 1996).

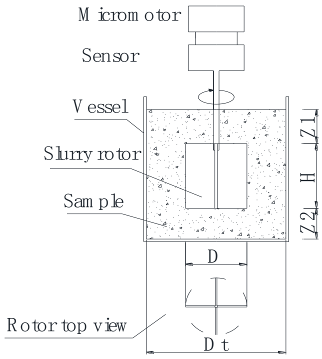

Figure 2 Vane detection method

The experiment selected rotor sizes H=4 cm, D=2 cm. Nguyen et al. (1985) propose that the container size and the insertion depth should be as follows: Dt/D > 2.0, Z1/D > 1.0, and Z2/D > 0.5 (shown in Figure 2).

$$T = \frac{\pi D^3}{2}\left(\frac{H}{D} + \frac{1}{3}\right)\tau_0 \tag{5}$$

Where:

T = the maximum torque of the blade, m·Nm;

D = the diameter of the blade, with the value of D being 20 mm;

H = the height of the blade, the value of H being 40 mm;

3 Experimental scheme

3.1 Material

The material features a particle density of 2.75 t/m^3, a bulk density of 1.75 t/m^3, a porosity of 36.6%, a dry tailings pH value of 8.74, and a pH value of the tailings mortar of 7.16, being weak alkaline. Particle distribution of the tailings is shown in Figure 3, with the non-uniformity coefficient of grain size being 61.17 and the percentage of particles under 20 µm being 38.23%.

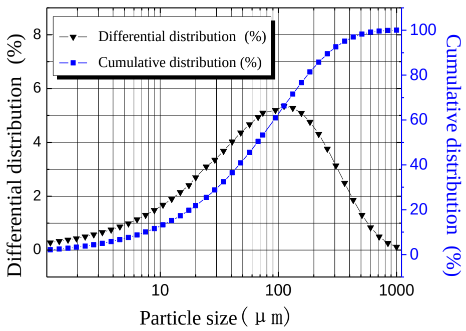

Figure 3 The particle distribution of tailings

3.2 Experimental method

3.2.1 Rheometer detection

Using the controlled shear stress method, when the rotor starts to rotate, the shear stress is the static yield stress to set shear stress from 0 to 300 Pa.

This experiment used the ordinary 500 mL beaker as the container (Dt = 8.5 cm, Z1 = 5.5 cm, and Z2 = 2 cm). In the preparation of the sample, Referring to the configurations in Nguyen (Nguyen and Boger, 1985), five samples were prepared with the concentrations of 72, 74, 76, 78, and 80%, their yield stress was measured.

3.2.2 L- Box experiment

- Unclassified tailings paste or slurry for preparing 6 L target concentrations in the bucket.
- Along the end slow down into L-Box; the time used is approximately 30 s.
- Waiting for the flow to stop; the maximum waiting time is 2 min.
- Detecting the flow distance L (The mean value of the maximum flow distance and the side wall flow distance).
- Every 5 cm, detecting the thickness of accumulated material and drawing the material accumulation profile.

4 Experimental results

4.1 Rheometer results

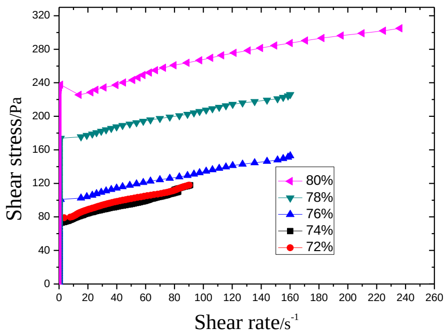

Figure 4 The test results from the rheometer

Bingham's rheological model (see Equation (5)) is used for the regression analysis of the experimental results shown in Figure 4:

$$\tau = \tau_0 + \mu\gamma \tag{6}$$

Where:

τ = shear stress, Pa;

τ_0 = yield stress, Pa;

μ = viscosity coefficient, Pa·s;

γ = shear rate, s^{-1};

Table 1 The yield stress and viscosity regression

Slurry concentration (%)	τ_0 (Pa)	μ (Pa·s)	R^2
80	225.1	0.363	0.98429
78	173.3	0.329	0.99679
76	100.3	0.329	0.99679
74	79.6	0.420	0.99201
72	73.4	0.459	0.99311

4.2 The test results from the rheometer

L-Box experiment is carried out to detect the slurry density. The flow profile curve is drawn with the flow distance as the abscissa and the initial height as the ordinate. The experimental results are shown in Figure 5 and Table 2.

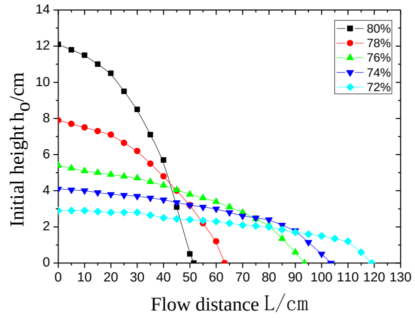

Figure 5 The L-Box test results

Table 2 The regression results of L-Box method

Unclassified tailings concentration (%)	Mortar density (g/cm)	Flow distance (L/cm)	Final height (h_0/cm)	τ_0 (Pa)
80	2.1	51.5	11.7	212.4
78	2.1	63.2	9.5	159.4
76	2.0	93.5	6.4	96.2
74	1.9	103.6	5.8	83.0
72	1.9	119.0	5.0	68.9

4.3 Comparison of experimental results

Figure 6 shows the comparison of the results obtained by the L-Box and rheometer:

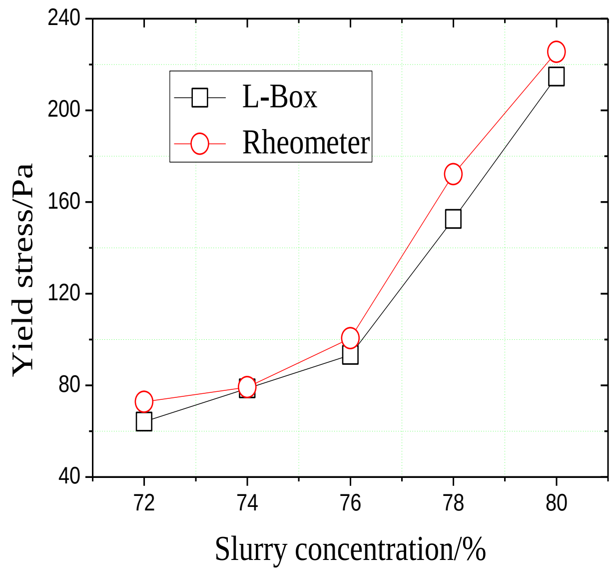

Figure 6 Concentration-yield stress profile

As shown in Figure 6, the yield stress of the material increases from 68.87~73.35 to 212.4~225.06 Pa when the concentration of the unclassified tailings paste increases within the range of 72~80%. Yield stress of slurry increases exponentially with concentration, indicating the former is greatly affected by the latter. When concentration increases from 76 to 78%, yield stress increases sharply (its average value increases from 96 to 162 Pa). In the vicinity of the concentration, the morphology of the tailings is more sensitive to concentration, i.e., a small increase in concentration can lead to a substantial increase of yield stress and pipe resistance.

As shown in Figure 6, the results of L-Box and vane-rheometer are almost identical and can verify each other, with those from the latter slightly greater (the deviation is 0.65~11.89%, with an average of 7.18%). In field operation, as it uses simple and convenient equipment, L-Box method features higher maneuverability and precision and is more economical.

The results were averaged, the yield stress values at each concentration were analyzed by regression analysis, and the relationship between yield stress and slurry concentration was obtained as follows:

$$y = 48.04 + 1.05 \times 10^{-39} x^{21.66} \tag{7}$$

$$y = 24191x^2 - 34869x + 12635 \tag{8}$$

Where:

y = yield stress, Pa;

x = slurry concentration, %;

R^2 = 0.9858 multiple correlation coefficient in the regression equation;

5 The calculation of frictional drag

The upward cut and fill method was used in the mine studied (located in Yunnan Province, China), in which the mined out area was filled using the unclassified tailings paste, cement and paste of coarse aggregate. For the independent areas, the edge of the ore body does not affect the special position of the mining cycle. No cement was used, and the downhole emission of unclassified tailings paste was used, with a backfill capacity of 60 m^3/h, a pipe diameter of DN150, a slurry concentration of 74~78% and transmission distance. The formula for calculating the on-way resistance is as follows:

$$i = \frac{16}{3d}\tau_0 + \frac{32v}{d^2}\mu_B \tag{9}$$

Where:

i = on-way resistance, MPa/km.

d = pipe diameter, mm.

v = flow rate of slurry in pipe, m/s.

According to the above experimental results, the concentration of the unclassified tailings paste is 74 to 78%. The calculated frictional drag is (3.4 to 6.6) Mpa/km when putting experimental results from Table 1 into Equation 9.

6 Conclusions

The yield stress of the material increases from 68.9~73.35 to 212.4~225.06 Pa when the unclassified tailings paste concentration was within the range of 72 to 80%. Yield stress of slurry increases exponentially with concentration.

Yield stress is significantly affected by concentration. When concentration increases from 76 to 78%, yield stress increases sharply (its average increases from 96 to 162 Pa). In the vicinity of the concentration, the morphology of the tailings is more sensitive to concentration, i.e., a small increase in concentration can lead to a substantial increase of yield stress and pipe resistance.

The results of L-Box and vane-rheometer are almost identical and can verify each other, with those from the latter slightly greater (the deviation is 0.65~11.89%, with an average of 7.18%). In field operation, as it uses simple and convenient equipment, L-Box method features higher maneuverability and precision and is more economical.

The calculated frictional drag is (3.39 to 6.6) MPa/km with a backfill capacity of 60 m^3/h, a pipe diameter of DN150, and a slurry concentration of 74~78%, with the unclassified tailings paste.

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